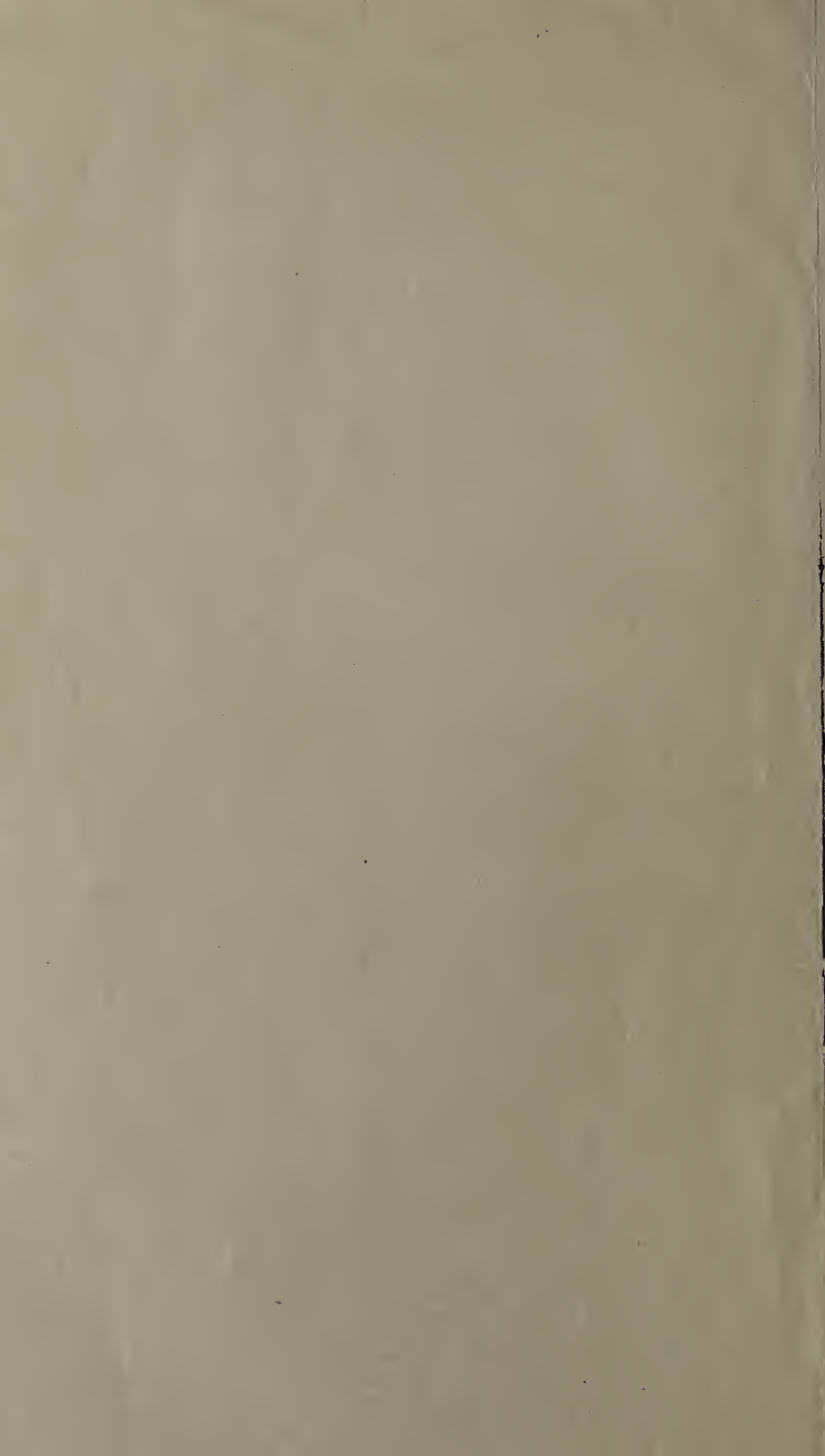


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# THE GEODES OF THE KEOKUK BEDS.

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ART. V.—*The Geodes of <sup>e</sup>the Keokuk Beds*; by FRANCIS  
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*Introduction.*

PROBABLY nowhere else in America do geodes attain such an exceptional development as in the Keokuk beds of the Central Mississippi Valley, and representative specimens of geodes from this region are now found in the mineral cabinets of many of the museums of the world. Apart from Professor Brush's preliminary examination and description of a few select specimens submitted to him in 1865 by A. H. Worthen, then director of the Geological Survey of Illinois, no study of these remarkable geodes has ever been made in spite of the fact that they bear a variety of metallic sulphides and promise to throw some light upon the origin of more important deposits of these minerals in sedimentary rocks showing no signs of igneous influence. The following brief report on their characteristics may therefore seem justified.

*Occurrence.*

The typical geode area is located in Southeastern Iowa and adjacent parts of Northeastern Missouri and Western Illinois. The most famous localities for geodes in this region are Keokuk and Lowell in Iowa; Wayland and St. Francisville in Missouri; and Warsaw and Niota in Illinois.

The age and stratigraphic relations of the geode-bearing beds are shown in the accompanying table:

System	Name of Formation		Thickness in feet
Pennsylvanian	Des Moines sandstone		0 — 50
	...disconformity.....		-----
	Pella limestone		0 — 30
Mississippian	...disconformity.....		-----
	St. Louis limestone		30 — 60
	...disconformity.....		-----
	Salem limestone		0 — 35
	...disconformity.....		-----
	Warsaw shale and limestone		40
	Keokuk	Geode bed	40
		Keokuk limestone	50
	Burlington limestone		75
	Kinderhook beds		150

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The geodes attain their maximum development in the Geode bed but some layers of the Keokuk limestone are geodiferous locally.

The Geode bed consists in its typical development of an impure, siliceous, dolomitic limestone at the base, usually containing large and well-developed geodes, followed by an argillaceous shale with more numerous but less perfectly developed geodes. Each subdivision is about twenty feet in thickness.

The composition of the lower subdivision of the Geode bed where it contains large and well-formed geodes at Keokuk, Iowa, is as follows:

Insoluble matter (largely free silica).....	33.80%
Fe <sub>2</sub> O <sub>3</sub> + Al <sub>2</sub> O <sub>3</sub> .....	2.80
CaCO <sub>3</sub> .....	39.99
MgCO <sub>3</sub> .....	12.50
Moisture and carbonaceous matter.....	7.70
Undetermined .....	3.21
<hr/>	
Total .....	100.00

In size the geodes range from about .2<sup>cm</sup> up to 75<sup>cms</sup> in diameter. But well-developed geodes of either extreme are rarely found. In general, the geodes of a given layer do not vary greatly in size at a given locality, but there may be considerable variation in this respect at different levels in the same exposure. Moreover, there may be marked changes in their dimensions at the same level at different localities. Often geodes of similar size are arranged roughly in bands parallel to the stratification. They usually lie with their longest diameter parallel to the bedding-planes, and at some localities they are closely associated with calcareous concretions of similar shape and size.

The abundance of the geodes in the geodiferous phase of the Keokuk formation is quite variable both laterally and vertically. At times they are so numerous in a given layer that their freedom of growth has been interfered with, and they are thus of very irregular shape. At other times, they may be so sparsely distributed through the rock that none may appear in an outcrop embracing several square yards. Again they may be absolutely wanting at some localities. The proportion of well-developed geodes in the beds varies greatly at different localities ranging from less than ten per cent at some places to more than ninety per cent at others.

As to the mineralogical relationship of the geodes to the containing rock, it is found that at any given locality each geodiferous layer as a rule bears geodes which are closely related among themselves, but which may be mineralogically

unlike those from other layers. But sometimes closely placed specimens in the same layer may bear very different minerals.

The contact relations of the geodes with the containing rock are not such as to indicate appreciable expansion during their formation. At no place is the inclosing rock found to be under any strain, nor is there any evidence of deformation of the layers at the contact. Rather the layers end abruptly where they abut into the geodes or exhibit a thinning where they pass immediately over or under them. The calcareous concretions which occur in the beds at some localities exhibit a similar relationship.

The extent of the geodes in the rock back from the outcrop is worthy of consideration. Bassler,\* in his discussion of the geodes of the Knobstone shales of Kentucky and Indiana, calls attention to the impervious nature of shale and inclines to the view that the geodes of that formation are confined to the surface or the immediate neighborhood of joint planes or rifts in the strata through which water had easy access. Such a relationship does not seem to hold for the geodes of the Keokuk beds.

#### *Mineralogy of the Geodes.*

Mineralogically, the geodes are almost invariably siliceous but a few calcareous geodes have been found. The siliceous types are characterized without exception by a thin outer shell of chalcedony and this is usually followed inwardly by crystalline quartz, but calcite may succeed the chalcedony. In some instances, however, the interior is lined with botryoidal chalcedony and no crystalline quartz nor calcite appears. At other times these minerals may all occur in a single geode, but usually only quartz and calcite or chalcedony and calcite are present. In addition the interior linings of the geodes are frequently studied with dolomite or ankerite, and one or more metallic sulphides are often represented. Moreover, some hollow siliceous geodes contain water, and in the vicinity of Niota, Illinois, many specimens are filled with black viscous bitumen. Finally others contain kaolin in the form of flocculent, white powder.

The primary minerals found in the geodes are: quartz, chalcedony, calcite, aragonite, dolomite, ankerite, magnetite, hematite, pyrite, millerite, chalcopryrite, sphalerite, kaolin, and bitumen. The alteration products represented are: limonite, smithsonite, malachite and gypsum.

With reference to the paragenesis, or order of deposition of the primary minerals, no constant order of succession holds for

\* Proc. U. S. Nat. Mus., vol. xxxv, p. 133 ff.

all geodes, and the same order of deposition may not obtain in two adjacent specimens.

For the purpose of illustrating the variations in the succession of the primary minerals in the geodes, the order of deposition in a number of typical specimens is given. The chalcedony of the shell is listed first in each case.

1. Chalcedony, quartz.
2. Chalcedony, quartz, chalcedony.
3. Chalcedony, quartz, chalcedony, quartz, chalcedony, pyrite, calcite with included pyrite.
4. Chalcedony, quartz, chalcedony, pyrite, calcite.
5. Chalcedony, quartz, chalcedony, pyrite, sphalerite.
6. Chalcedony, quartz, dolomite, calcite.
7. Chalcedony, quartz, magnetite, hematite
8. Chalcedony, calcite, calcite.
9. Chalcedony, calcite, millerite.
10. Chalcedony, quartz, ankerite, calcite, aragonite.
11. Chalcedony, quartz, calcite, bitumen.
12. Chalcedony, calcite with included chalcopryrite.
13. Chalcedony, quartz, pyrite, magnetite.
14. Chalcedony, chalcedony, sphalerite.

First, then, in the development of the siliceous geodes there was formed a thin chalcedonic shell. Upon this is superimposed quartz, either in the crystalline or chalcedonic condition, or calcite. It is a remarkable fact that when calcite and quartz appear in the same specimen the calcite is normally subsequent to the quartz, which rests directly on the siliceous shell. This relationship, first pointed out by Professor Brush,\* has been found to hold in every instance by the writer, but A. H. Worthen claims to have found a single specimen at Keokuk "in which large crystals of calcite are partly covered with smaller crystals of quartz."†

The alternation of crystalline quartz and chalcedony in some of the geodes is difficult to account for. If the layers were all formed during one period of growth as seems probable, changes in the condition and amount of silica supplied may have given rise to the phenomenon. Changes in temperature or pressure cannot be appealed to, because adjacent quartz geodes in the strata frequently do not show the same alternations.

The position of calcite in the geodes is subject to many variations. At times it succeeds the chalcedonic shell directly, but more often it rests upon an inner lining of quartz or chalcedony. In some of the geodes, calcite of two generations appears. The earlier calcite is often discolored brownish, and is frequently associated with or directly followed by sphalerite,

\* Geological Survey of Illinois, vol. i, p. 90, 1866.

† Idem, p. 90.

millerrite, chalcopyrite or pyrite. Intervening between this calcite and that of younger age, crystals of dolomite or ankerite are also sometimes found.

### *Origin of the Geodes.*

The origin of the geodes of the Keokuk beds has long been a disputed question, and, although there has been considerable speculation upon the subject, no one theory of their development has, as yet, been widely held.

The existence of perfectly developed geodes in strata often very impervious to underground circulation furnishes a problem which is exceedingly difficult to solve. The containing rock in the Keokuk region is often highly argillaceous and no structures which might serve as passage ways for mineralizing solutions are to be seen.

It was formerly believed that the geodes were formed by the deposition of mineral matter on the walls of cavities formed by the solution of sponges imbedded in the rocks. Thus, Dana states:\*

“They have been supposed to occupy the centers of sponges that were at some time hollowed out by siliceous solutions, like the hollowed corals of Florida, and then lined with crystals by deposition from the same or some other mineral solution.”

This theory has had many followers and S. J. Wallace has even gone so far as to coin a generic name for the sponge whose solution is supposed to have afforded the cavities in which the geodes were developed.† To this genus, called *Biopalla*, eight species were referred upon the basis of difference in size, shape, and surface markings of the geodes. The sponge hypothesis, however, is not now widely held. No evidence of sponges capable of giving rise to geodes have ever been found in the Keokuk beds. Moreover, the geodes vary widely in size and shape, a fact which argues strongly against any theory which presupposes such an origin. Many specimens are nodular and irregularities of the greatest variety characterize their exterior form. It may safely be said that no two of them assume exactly the same proportions.

Professor Shaler, in a paper entitled “Formation of Dikes and Veins,”‡ also devotes some space to the development of geodes and, although his studies were based upon geodes known to be of fossil origin which occur in the Knobstone shales of Kentucky, his conclusions may well be considered at this point:

\* Manual of Geology, 4th ed., pp. 97, 98, 1895.

† This Journal (3), vol. xv, p. 366 ff., 1878.

‡ Bull. Geol. Soc. Am., vol. x, p. 253 ff., 1899.

"Normal geodes are hollow spheroids and are generally found in shales. They clearly represent, in most cases, a segregation of silica, which has evidently taken place under conditions of no very great heat, brought about by deep burial beneath sediments or other sources of temperature. It is difficult in all cases to observe the circumstances of their origin, but in certain instructive instances this can be traced. It is there as follows: Where in a bed in which the conditions have permitted the formation of geodes the calyx of a crinoid occurs, the planes of junction of the several plates of which it is composed may become the seat of vein-building. As the process advances these plates are pushed apart and in course of time enwrapped by the silica until the original sphere may attain many times its original diameter and all trace of its origin lost to view, though it may be more or less clearly revealed by breaking the mass.

In the process of enlargement which the geodes undergo they evidently provide the space for their storage by compressing the rock in which they are formed. In the rare instances where I have been able to clearly observe them in their original position they were evidently cramped against the country rock, the layers of which they had condensed and more or less deformed. Although when found upon the talus slopes or the soil these spheres usually contain no water in their central cavities, these spaces are filled with the fluid while they are forming and so long as they are deeply buried. There can be no doubt that this water is under a considerable though variable pressure.

The conditions of formation of spheroidal veins or geodes clearly indicate that an apparently solid mass of crystalline structure may be in effect easily permeated by vein-building waters, and this when the temperature and pressure could not have been great. It is readily seen that the walls of these hollow spheres grow interstitially while at the same time the crystals projecting from the inner side of the shell grow toward the center. We, therefore, have to recognize the fact that the siliceous water penetrated through the dense wall. In many of these spherical veins we may note that the process of growth in the interior of the spheres have been from time to time interrupted and again resumed. These changes may be due to the variations in pressure to which the water in the cavities is necessarily subjected as the conditions of its passage through the geode-bearing zone are altered."

More recently Bassler has written\* on the formation of the Knobstone geodes. He says:

"The majority of geodes in the Knobstone group may be traced directly or indirectly to a crinoidal origin for the simple reason that these strata are often crowded with the fragments of this class of organisms. Probably next in order as a geode maker is the common brachiopod *Athyris lamellosa*, but no class of

\* Proc. U. S. Nat. Mus., vol. xxxv, p. 133 ff., 1908.

fossil is exempt from replacement by silica when the proper conditions obtain."

Bassler is of the opinion that the Keokuk geodes may have the same mode of origin as those of the Knobstone. But he disagrees with Shaler as to the details of geode development. Thus:

"Returning to the suggestion in Dana's Manual of Geology that the Keokuk geodes are hollowed out sponges lined with crystals it seems more reasonable, in view of the absence of such sponges in that formation and the presence of numerous specimens indicating the origin described above, that the latter is nearer the truth. Prof. Shaler's idea that this class of geodes is formed when deeply buried is not in accord with the facts, nor does there appear to be any necessity for the water of formation to be under a considerable though variable pressure. Ordinary surface waters charged with silica seem to be sufficient."

This generalization in so far as it relates to the geodes of the Keokuk beds in the region studied, would seem to be too broad. Out of several thousand geodes examined from the Keokuk beds only one, which had plainly been formed by the enlargement of a specimen of the crinoid *Barycrinus*, showed evidence of this method of geodization.

The origin of the Keokuk geodes in the region studied is believed by the writer to be related to the calcareous concretions which originally must have been very abundant in the beds and which are still preserved at some localities. These nodules, being more soluble than the inclosing rocks, have been in large part removed, thus affording cavities in which the geodes could be formed. Where still preserved, the concretions have exactly the same relationship to the containing rock as the geodes and possess analogous shapes. They were obviously formed on the sea-bottom while the strata were being deposited, since lines of stratification do not pass through them and no evidence of expansion is encountered about their borders. The process of solution seems to have started in the interior and proceeded outwards. That this was the method of removal is indicated by the occurrence, in the beds, of some geodic nodules whose interiors were only partially hollowed out when deposition began. Carbonic acid and sulphuric acid, of which the latter must have been generated by the decomposition of the pyrite so common in the beds, were probably the most active solvents.

The white powder of kaolin found in some of the geodes is thought to represent, at least in part, a residual product resulting from the leaching of the original argillaceous content of the nodules. That kaolin can be so formed is clearly indicated

by the presence of this mineral so related to impurities in some of the nodules that its derivation cannot be questioned. The more common occurrence of kaolin in the geodes from the more argillaceous portion of the beds is significant in this connection. Moreover, the great majority of the geodes which contain kaolin are imperfectly developed and the calcite of such specimens invariably includes the white powder of this mineral. These facts strongly support the idea that the kaolin must be a residual product.

Concerning the time of formation of the geodes, little is definitely known. The removal of the calcareous nodules which, it is assumed, preceded the geodes, implies an interval of solvent action during which the Keokuk beds were above ground-water level. Such a condition must have obtained during the period of denudation which succeeded the deposition of the St. Louis limestone. Some solvent action must also have been inaugurated during the pre-Salem and post-Salem emergences but these were of limited duration. The growth of geodes, on the other hand, undoubtedly took place below ground-water level.

In the development of the geodes at least two periods of mineralization are involved. The first period of development was by far the most important. During this period of growth the quartz, chalcedony dolomite, and a considerable amount of the calcite together with almost all of the metallic sulphides were deposited. This period of mineralization possibly took place during the interval which just preceded the Pennsylvanian inundation. The region was certainly near base level at this time and the Keokuk beds must have been below ground-water level. The occurrence of geodes, supposedly derived from the Keokuk beds, in the basal Pennsylvanian conglomerate in Indiana, where similar conditions probably prevailed, supports this view.

Of the minerals of the second period of growth, transparent crystals of calcite and slender, untarnished flakes of pyrite are by far the most important. The minerals of this class are doubtless much younger than those of the former as suggested by the fact that in the same geode the pyrite associated with the newer calcite is often perfectly fresh while the earlier pyrite is badly decomposed.

The secondary minerals of the geodes such as limonite, gypsum, smithsonite, and malachite are for the most part of much more recent origin. They have resulted from the alteration of the primary sulphides as shown by their association with the partially decomposed members of this group.

The bitumen which occurs in some of the geodes must have been introduced sometime after their formation, since it has not interfered with the normal geode development.

The process of geodization evidently consisted of the inward growth of crystals upon the inside walls of cavities left by the solution of the imbedded concretions. The growth was necessarily accomplished by deposition from a solution which filled the interior completely. As this solution became depleted in its mineral content, more was introduced by some process of diffusion and a continuous deposition resulted. In some instances a very impervious wall was developed and growth must have been extremely slow. But in the majority of geodes numerous feeding channels in the walls afforded ready passage to the solutions after they penetrated the siliceous shells.

The mineralogical variation of geodes which may occur in close proximity to each other is difficult to account for. It must either be assumed that the process of geodization was a very local one and that each individual geode possessed only a small sphere of attraction, or that a peculiar localization of conditions favored in some instances the deposition of mineral matter more widely diffused through the mineralizing solutions.

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